Great Basin Naturalist 55(2), © 1995, pp. 158–163

DOUGLAS-FIR TUSSOCK MOTH (*ORGYIA PSEUDOTSUGATA* MCDUNNOUGH) ON SUBALPINE FIR IN NORTHERN UTAH

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ABSTRACT.—Douglas-fir tussock moth (*Orgyia pseudotsugata* McDunnough) defoliation was detected by aerial survey on three areas of the Wasatch-Cache National Forest in 1990 and 1991. These are the first documented tussock moth outbreaks in Utah. Ground surveys revealed that subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) was heavily defoliated during the outbreak. Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), though a minor component in the affected areas, had noticeably less defoliation and mortality. Adjacent stands of Douglas-fir had little or no visible tussock moth activity. Defoliation on subalpine fir was typically found evenly distributed throughout the crown rather than concentrated at the top. Ninety-four percent of subalpine fir with defoliation ratings of 90% or more were killed. Top-kill occurred on nearly one-half of subalpine firs defoliated 25–89%. Heavily defoliated trees tended to occur in pockets bounded by areas of light defoliation. After three consecutive years of defoliation, tussock moth populations collapsed. No life stages were detected in 1993 from visual inspections of foliage or in pheromone traps.

Key words: tussock moth, subalpine fir, defoliators, Douglas-fir, Utah forests, forest insects.

The Douglas-fir tussock moth (*Orgyia pseudotsugata* McDunnough) is a significant defoliator of Douglas-fir and true firs throughout its host range in western North America. Tussock moth outbreaks on the Wasatch-Cache National Forest, UT, from 1990 to 1992 were unique because subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) experienced greater defoliation and mortality than Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco). These tussock moth infestations are the first documented outbreaks in Utah (Ollieu 1978, Tunnock et al. 1985).

Previous tussock moth outbreaks indicate three primary hosts depending on location. In British Columbia and northern Washington, Douglas-fir is preferred; in southern Washington, Oregon, and Idaho, Douglas-fir, white fir (*Abies concolor* [Gord. and Glend.]), and grand fir (*A. grandis* [Dougl.] Lindl.) are preferred; in California, Nevada, Arizona, and New Mexico, white fir is preferred (Wickman et al. 1981). In these areas subalpine fir and other members of the pine family are typically defoliated after the preferred host is consumed. The Wasatch-Cache National Forest outbreaks experienced light defoliation of Douglas-fir within stands of completely defoliated subalpine fir.

Interestingly, the first record of tussock moth defoliation in the United States was on subalpine fir at Jarbidge, NV, in 1927 (Balch 1930). Affected areas were of subalpine fir occurring either purely or in mixture with limber pine (*Pinus flexilis* James). These two conifers and quaking aspen (*Populus tremuloides* Michx.) formed virtually the entire forest at Jarbidge (Balch 1932) in contrast to the Utah sites that contain or are surrounded by substantial Douglas-fir. Balch's records are the only literature indicating subalpine fir to be a principal host, while more recent authors consider the species to be secondary (Wickman et al. 1981, Berryman 1988).

The objective of this study was to document the effects of these outbreaks on subalpine fir. Information will be used to predict future impacts of tussock moth defoliation on subalpine fir resource. This report summarizes stand conditions following infestation and attempts to characterize the effects of defoliation on individual trees.

METHODS

Aerial detection surveys delineated tussock moth activity near the Baxter Sawmill site, Ogden Ranger District, Wasatch-Cache National Forest, UT, in 1990. Additional infestations

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were detected at Blind Hollow and Amazon Hollow, Logan Ranger District, Wasatch-Cache National Forest, UT, in 1991. Subsequent ground surveys confirmed tussock moth populations at these locations.

A total of 35 pairs of 20 basal-area-factor variable plots and 1/300 ac seedling/sapling fixed plots were established in July 1992 at the three areas. Plots were installed along a transect at 100-m intervals starting from a reference point in areas with visible defoliation. No other attempt was made to randomize plot locations or to cover the entire affected area. Tree data collected include species, diameter at breast height (DBH), height, age, 5- and 10-year radial growth, insect/disease damage, and an ocular estimate of percent defoliation. Additionally, the distal 18 inches of three randomly selected lower crown branches on all host species were examined for pupae or egg masses.

Plots were remeasured in July 1993 to evaluate changes in insect-related tree injury and mortality, percent defoliation, and presence of tussock moth life stages. One pair of plots at Baxter Sawmill was cut and lost during salvage operations. To maximize data-collection consistency, the same individual conducted defoliation estimates on 32 of 35 plots for plot establishment and remeasurement.

INDIDS, the insect and disease damage survey program (Bousfield et al. 1985), was used to calculate per-acre average stand characteristics. Individual tree defoliation ratings were classified into the five categories of Weatherby et al. (1992): (1) undamaged, (2) lightly defoliated (1–24% of total needle complement defoliated), (3) moderately defoliated (25–74%), (4) heavily defoliated (75–89%), and (5) very heavily defoliated (90+%). Defoliation ratings from 1992 and 1993 were used to determine defoliation effects on tree condition.

RESULTS

Blind Hollow

Prior to the outbreak, composition of all live trees greater than 5 inches DBH was 69% subalpine fir, 28% aspen, and 3% Douglas-fir. Total pre-outbreak live basal area was 178.9 sq ft/ac. By 1993 live basal area was reduced to 166.8 sq ft/ac. Site elevations range from 7800 to 8100 ft. Aspect ranges from southwest to south to east on slopes varying from 10 to 50%.

Subalpine fir seedlings and saplings (0–4.9 inches DBH) were significantly affected by tussock moth. Sixty stems per acre in this size class representing 25% of the stocking were killed (Table 1). Pole-sized subalpine fir (5–8.9 inches DBH) were more frequently defoliated than larger diameter classes. Fifty-eight percent of stems 5–8.9 inches DBH, 34% of stems 9–11.9 inches DBH, and 39% of stems ≥12 inches DBH were defoliated. Stems exhibiting top-kill increased proportionately with percent defoliation. Four percent of subalpine fir stems over 5 inches DBH were killed by tussock moth.

In the ≥12-inches diameter class, none of 7.3 Douglas-fir per acre were visibly defoliated (Table 1). Among subalpine fir in this class, 3% of 65.1 per acre were defoliator killed. Twenty-eight percent survived defoliation, while 69% were not visibly defoliated.

Western balsam bark beetle (*Dryocoetes confusus* Swaine) killed 4.9 subalpine fir stems per acre. These trees were attacked in 1991, coinciding with the peak of the tussock moth outbreak.

TABLE 1. Trees per acre condition summary of subalpine fir and Douglas-fir following a Douglas-fir tussock moth outbreak, Blind Hollow, Wasatch-Cache National Forest, July 1993. Summary calculated from 10 variable/fixed plot pairs. SAF = subalpine fir, DF = Douglas-fir.

Diameter class	Undamaged		Defoliation class: Light		Moderate		Heavy		Very heavy		Mortality	
	SAF	DF	SAF	DF	SAF	DF	SAF	DF	SAF	DF	SAF	DF
0–4.9″	30.0	0.0	120.0	0.0	30.0	0.0	0.0	0.0	0.0	0.0	60.0	0.0
5–8.9″	39.0	0.0	16.0	0.0	18.5	0.0	6.0	0.0	6.2	0.0	6.0	0.0
9–11.9″	25.9	2.9	7.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12″ +	40.0	7.3	13.4	0.0	4.8	0.0	0.0	0.0	0.0	0.0	2.1	0.0

The 1992 survey found an average of 3.1 pupae and 0.5 egg masses per three-branch samples. The 1993 survey found no current life stages on any sample tree, and no life stages were visible in the area.

Baxter Sawmill

Prior to the outbreak, composition for all live trees greater than 5 inches DBH was 65% subalpine fir, 25% aspen, and 10% Douglas-fir. Total live basal area was 176.1 sq ft/ac at the onset of the outbreak. Live basal area in 1993 was 112.8 sq ft/ac. Site elevations range from 7400 to 7900 ft. Aspect is south, southwest, west, and northwest on slopes varying from 10 to 30%.

Subalpine fir seedlings and saplings had considerable defoliator damage. More than 250 seedlings and saplings per acre, or 55% of stocking in this size class, died (Table 2). Most surviving seedlings and saplings were only lightly defoliated. Forty-nine percent of subalpine fir stems 5.0–11.9 inches DBH were killed by tussock moth. Trees with top-kill increased proportionately with percent defoliation. Only 3% of subalpine fir stems in the lightly defoliated category experienced top-kill, compared to 92% of surviving trees in the heavily and very heavily defoliated classes.

In the ≥12-inches diameter class, Douglas-fir had 10% of 22.6 trees per acre defoliator killed. Fifty-seven percent were not defoliated, with another 33% defoliated but surviving (Table 2). Among 38.5 subalpine fir per acre in this size class, 7% were defoliator killed and 77% were defoliated but survived.

Western balsam bark beetle has also been active at Baxter Sawmill, killing 38.2 subalpine fir per acre, mostly in 1990 or 1991. Annosus root disease (*Heterobasidion annosum* [Fr.] Bref.) was found on 4.6 subalpine fir per acre.

The 1992 survey found an average of 4.8 pupae and 1.2 egg masses per three branches sampled. No current life stages were found in 1993 on the plots or in the area. Additionally, no tussock moths were caught in pheromone traps placed in the Baxter Sawmill area in 1993.

Amazon Hollow

Prior to the outbreak, composition of all live trees greater than 5 inches DBH was 73% subalpine fir, 24% aspen, 2% Douglas-fir, and 1% lodgepole pine. Total live basal area was 125.5 sq ft/ac at the onset of the outbreak. Live basal area in 1993 was 72.2 sq ft/ac. Site elevations range from 7500 to 7800 ft. Aspect is east on slopes varying from 10 to 25%.

One-hundred subalpine fir seedlings and saplings per acre, or 10% of stocking in that class, were killed (Table 3). Mortality in the three size classes greater than 5 inches DBH ranged from 50 to 62%. Top-kill was common for all defoliation intensities. Of the surviving defoliated subalpine fir (>5 inches DBH), 60% had top-kill, including 63% of stems classified as lightly defoliated.

In the ≥12-inches size class, 28% of 4.3 Douglas-fir per acre were defoliator killed with another 16% defoliated but surviving (Table 3). Among 29.7 subalpine fir per acre in that class, 50% were defoliator killed and another 31% were defoliated but survived.

Western balsam bark beetle killed 2.6 subalpine fir per acre. Annosus root disease was found on 4.2 trees per acre.

The 1992 survey found 2.0 pupae and 0.6 egg masses per three branch samples. The 1993 survey failed to detect any current life stages.

Sample Tree Summary

Two-hundred ninety-one host sample trees were rated for defoliation and monitored for

TABLE 2. Trees per acre condition summary of subalpine fir and Douglas-fir following a Douglas-fir tussock moth outbreak, Baxter Sawmill, Wasatch-Cache National Forest, July 1993. Summary calculated from 13 variable/fixed plot pairs. SAF = subalpine fir, DF = Douglas-fir.

Diameter class	Undamaged		Defoliation class: Light		Moderate		Heavy		Very heavy		Mortality	
	SAF	DF	SAF	DF	SAF	DF	SAF	DF	SAF	DF	SAF	DF
0–4.9″	23.1	0.0	138.5	0.0	23.1	0.0	23.1	0.0	0.0	0.0	253.5	0.0
5–8.9″	12.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	29.3	0.0
9–11.9″	2.5	0.0	7.8	0.0	2.5	0.0	2.1	0.0	0.0	0.0	25.0	0.0
12″ +	3.4	12.8	17.9	6.5	2.7	1.0	0.0	0.0	1.3	0.0	2.7	2.2

TABLE 3. Trees per acre condition summary of subalpine fir and Douglas-fir following a Douglas-fir tussock moth outbreak, Amazon Hollow, Wasatch-Cache National Forest, July 1993. Summary calculated from 12 variable/fixed plot pairs. SAF = subalpine fir, DF = Douglas-fir.

Diameter class	Undamaged		Defoliation class: Light		Moderate		Heavy		Very heavy		Mortality	
	SAF	DF	SAF	DF	SAF	DF	SAF	DF	SAF	DF	SAF	DF
0–4.9″	500.0	0.0	275.0	0.0	75.0	0.0	0.0	0.0	25.0	0.0	100.0	25.0
5–8.9″	6.8	0.0	13.4	0.0	4.3	0.0	0.0	0.0	0.0	0.0	40.4	0.0
9–11.9″	5.0	0.0	9.5	0.0	3.1	0.0	0.0	0.0	0.0	0.0	23.0	0.0
12″ +	5.7	2.4	5.5	0.4	0.7	0.3	1.2	0.0	1.8	0.0	14.8	1.3

survival (Tables 4, 5). Defoliator-caused mortality was found to increase with the degree of defoliation. In the very heavily defoliated class, 94% of subalpine firs and 100% of Douglas-firs were killed. None of the sample trees in the lightly defoliated class were killed. Incidence of top-kill also increased with degree of defoliation, although trees in the heavily and very heavily defoliated classes were more likely to succumb than exhibit top-kill. This parallels other tussock moth study results, where degree and incidence of top-kill is related to severity of defoliation (Wickman 1978).

Surviving defoliated trees began to recover by 1993 (Tables 4, 5). Average defoliation rating for lightly defoliated subalpine fir in 1992 was 7.7%. In 1993 the same trees had an average rating of 3.9% with no visible defoliation of that year's needles. The other defoliation classes for subalpine fir and Douglas-fir had similar recoveries. Some of the most dramatic recoveries, however, can be partially attributed to the most heavily defoliated trees of their respective classes succumbing and therefore not being rated in 1993.

DISCUSSION

Although Douglas-fir tussock moth had been previously captured in pheromone traps in Utah, the Wasatch-Cache outbreaks are the first to be documented in the state (Tunnock et al. 1985). More significantly, a literature review revealed the Wasatch-Cache outbreaks to be unique in that subalpine fir is apparently the preferred host type. Balch's (1930, 1932) studies are the only that list subalpine fir as a primary host. More recent literature indicates subalpine fir to be secondary to Douglas-fir, white fir, or grand fir (Wickman et al. 1981, Johnson and Lyon 1988). At the Wasatch-Cache outbreaks, subalpine fir appears to be preferred over Douglas-fir. All three study sites are in close proximity to stands where Douglas-fir is the primary overstory component. These Douglas-fir stands experienced little or no visible defoliation. This contrasts to Balch's Jarbidge, NV, site where subalpine fir, limber pine, and quaking aspen "form practically the whole of the forest" (Balch 1932).

Another exception to the tussock moth's preference for Douglas-fir, white fir, or grand fir has been observed in urban areas along the Colorado Front Range. In these cases blue spruce (*Picea pungens* Engelm.) has been the preferred host over white fir and Douglas-fir (D. Leatherman[2], personal communication). In Colorado's native forests Douglas-fir is the principal host.

The defoliation pattern seen on the Wasatch-Cache National Forest outbreaks differed greatly from previously recorded patterns, such as in Oregon's Blue Mountains. Wickman (1978) recommends estimating defoliation "according to the percent of crown totally defoliated from the top down." That technique was abandoned for this study because most needle loss was distributed evenly throughout the crown rather than concentrated at the top. Application of Wickman's method would have misrepresented many trees with significant defoliation by having them rated at ≤10% defoliation. In other words, the Wasatch-Cache National Forest outbreaks did not fit the "top down" defoliation pattern observed in other outbreaks (J. Weatherby[3], personal communication).

This study indicates that subalpine fir may be locally more susceptible to tussock moth mortality than either grand fir or Douglas-fir. Despite the difference in percent defoliation

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[3]Entomologist, USDA Forest Service, Forest Pest Management, Boise, Idaho.

TABLE 4. Condition of subalpine fir sample trees within tussock moth monitoring plots at Blind Hollow, Baxter Sawmill, and Amazon Hollow, Wasatch-Cache National Forest, July 1993.

Defoliation class[1]	Class limits (% defoliation)	Average 1992 defoliation (% defoliation)	Average 1993 defoliation[2] (% defoliation)	Total no. of trees	Top-kill #	Top-kill %	Mortality #	Mortality %
Undamaged	0.0	0.0	0.0	51	0	0	0	0
Light	1–24	7.7	3.9	71	7	10	0	0
Moderate	25–74	39.5	36.3	31	14	45	3	10
Heavy	75–89	77.5	77.5	9	2	22	5	55
Very heavy	>90	91.3	72.5	63	2	3	59	94

[1]Trees assigned defoliation class based on 1992 defoliation ratings.
[2]Surviving trees from 1992 defoliation class.

TABLE 5. Condition of Douglas-fir sample trees within tussock moth monitoring plots at Blind Hollow, Baxter Sawmill, and Amazon Hollow, Wasatch-Cache National Forest, July 1993.

Defoliation class[1]	Class limits (% defoliation)	Average 1992 defoliation (% defoliation)	Average 1993 defoliation[2] (% defoliation)	Total no. of trees	Top-kill #	Top-kill %	Mortality #	Mortality %
Undamaged	0.0	0.0	0.0	17	0	0	0	0
Light	1–24	6.5	2.0	20	0	0	0	0
Moderate	25–74	40.0	21.7	3	0	0	0	0
Heavy	75–89	80.0	65.0	2	0	0	1	50
Very heavy	>90	95.0	—	3	0	0	3	100

[1]Trees assigned defoliation class based on 1992 defoliation ratings.
[2]Surviving trees from 1992 defoliation class.

estimation techniques, the Wasatch-Cache results can be compared to those of Wickman (1978). At the 90% defoliation level, Wickman found 24% grand fir mortality and 30% Douglas-fir mortality (90% defoliation in Wickman's study means complete defoliation in the top 90% of the live crown). At the Wasatch-Cache outbreaks, 57% of subalpine fir defoliated at 90% were killed (90% defoliation using the methodology of this study means that 90% of the estimated total needle complement was consumed). At the 99% defoliation level, Wickman found that grand fir died at 53% and Douglas-fir at 46%. This compares to 96% mortality on Wasatch-Cache subalpine fir rated at 95% defoliation.

Within the infested study areas, the degree of damage varies greatly from one plot to the next. One plot at Amazon Hollow had all host type defoliator killed, while a plot 100 m distant was only lightly defoliated. Although the very heavily defoliated areas are restricted in size (usually less than 5 ac), the amount of mortality in these pockets is substantial. An area not sampled, at Baxter Sawmill due to salvage logging operations, included over 20 ac where virtually all host type was killed. Many of these areas are bounded by stands of similar composition and density that were only lightly defoliated. In a study of five case histories in Oregon and California, Wickman et al. (1973) found almost one-half of tree mortality occurring in patches coinciding with high moth population centers.

Douglas-fir tussock moth outbreaks typically span two to four years. Moth populations develop rapidly and then abruptly subside after only one to two years of outbreak populations (Wickman et al. 1981). The Wasatch-Cache outbreaks have followed this pattern. Moderate to heavy defoliation at Baxter Sawmill was first detected from aerial survey in 1990; defoliation was very heavy in 1991. In 1992 moth activity dramatically declined, and in 1993 no life stages were discovered by either visual inspection or pheromone trapping.

While it is beyond this study's scope to identify causal agents that initiated the Wasatch-Cache outbreaks, it should be noted that a prolonged drought coincided with the infestation. Most damage occurred on drier sites, such as ridge tops and southerly facing slopes.

This corresponds to patterns seen in other outbreaks (Bergstrom 1980). The affected trees were apparently drought stressed at the time of defoliation. The sudden moth population collapse mimics that of other outbreaks where a nuclear polyhedrosis virus appears to be the major mortality factor (Wickman et al. 1973).

CONCLUSION

Although uncommon, Douglas-fir tussock moth can cause considerable damage to subalpine fir. While damage in the three study areas was variable, pockets of heavy defoliation had substantial subalpine fir mortality. Larger-diameter trees are apparently less susceptible to mortality except in these pockets where virtually all host type was killed. Although a minor component in the heavily defoliated areas, locally Douglas-fir appears to be less-preferred host material. All study areas are in close proximity to Douglas-fir stands that exhibited little or no tussock moth activity. Western balsam bark beetle and annosus root disease contributed to subalpine fir mortality, though visibly minor relative to defoliator impacts. While forecasting losses in volume would be difficult based on this study, the fate of individual trees can be reasonably predicted given degree of defoliation.

ACKNOWLEDGMENTS

I am grateful for the many people who helped with this project. David Leatherman (Colorado State Forest Service), Julie Weatherby, Steve Munson, and John Anhold (all Forest Pest Management, Intermountain Region) provided critical review of the manuscript. Alan Dymerski, John Guyon, Dawn Hansen, John Anhold, Valerie DeBlander (all Forest Pest Management, Intermountain Region), Jill Ansted, Craig Yanase, and Lisa Robinson (all Utah Department of Agriculture) assisted with data collection. Julie Weatherby and John Anhold provided input for the survey design. Dawn Hansen, Cindy Hampton, John Guyon, and Bent Olsen (all Forest Pest Management, Intermountain Region) helped with data processing, table preparation, and editing. Irene Voit (Intermountain Research Station) assisted with the literature search.

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Received 21 April 1994
Accepted 14 November 1994